Caregiver communication to the child as moderator and mediator of genes for language

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Abstract

Human language appears to be unique among natural communication systems, and such uniqueness impinges on both nature and nurture. Human babies are endowed with cognitive abilities that predispose them to learn language, and this process cannot operate in an impoverished environment. To be effectively complete the acquisition of human language in human children requires highly socialised forms of learning, scaffolded over years of prolonged and intense caretaker-child interactions. How genes and environment operate in shaping language is unknown. These two components have traditionally been considered as independent, and often pitted against each other in terms of the nature *versus* nurture debate. This perspective article considers how innate abilities and experience might instead work together. In particular, it envisages potential scenarios for research, in which early caregiver verbal and non-verbal attachment practices may mediate or moderate the expression of human genetic systems for language.

Keywords: attachment; child-directed speech; epigenetics; Gene x Environment interaction; caregiver-child interaction; language development.

1. Introduction

Many living species have evolved elaborate communication systems over millions of years [1], yet human language is recognised as a form of communication unique to *homo sapiens*. Because of this unique species trait, several researchers have postulated that the human language faculty must somehow depend on a species-specific genetic component. Yet the specific genetic bases of language are still largely unknown, and are now being explored with the advent of genetic methods. The evidence so far has mainly highlighted possible genetic bases for developmental language disorders, and in a few instances certain genes have been linked to earlier or faster language development in normally developing children. Because language is a complex trait, it is likely that many genetic systems support its development, whether in typical or atypical populations [2]. Likewise, genes that participate in the language phenotype are likely to regulate several other non-linguistic abilities and functions [3].

Human language is also unique as a system of communication in the animal kingdom in that it is a learned activity requiring massive exposure and intense socialisation with multiple tutors. It takes children at least their first 5 years of life to be able to communicate fluently. For robust language abilities to emerge, sustained socialisation and interaction between the child and primary caregivers are fundamental. Thus, besides basic innate capabilities, the language environment appears critical to the life-course trajectory of a child. Researchers emphasising the contribution of the social environment to language have discovered that quantity, content, and quality of language input all dramatically affect child language development [4]. Large differences in linguistic skills emerge very early during infancy and childhood, and persist throughout the life of an individual into adolescence [5] [6]. For example, language development of normally developing children raised by more educated parents is faster and more elaborate - in terms of lexical richness, the number and type of words they know, and other measures- than that of children raised by less educated parents [7]. Again, when language acquisition is compared to the process of acquiring a communication system in other species, no other system in the natural kingdom is known to require the scale and intensity of human socialised learning effort.

Human language thus appears to be a unique form of communication both in terms of its possible genetic bases and its cultural requirements for acquisition and transmission. Perhaps for this reason, language has been a bone of contention in the nature-nurture debate, and researchers have taken sides by placing emphasis on either the genetic component or the socio-cultural component. In this perspective article we consider the third option that genes and environment may mutually interact in language development, at least on the level of ontogenetic development (we leave aside the topic of phylogenetic co-evolution of language and genes; see [8]). Given the crucial role of social experience for language development, and that language has a genetic component, what are the possible gene-environment consequences of differential social styles of attachment and interaction the child is immersed in? With a view to better understanding the genetic basis of language, here we are interested in charting possible yet to be explored gene-environment interactions for language. As most research to date has focused on individuating genetic mutations or genetic expressions related to language disorder phenotypes, little is known on what genetically determines individual differences in normally developing children, and even less is known on the influence of the social and linguistic input to the child on genetic expression of genes implicated in language. It is possible that because language is a highly complex human behaviour composed of multiple integrated cognitive, perceptual, and social skills, gene-environment interactions for genes that do not directly regulate language but regulate for example the expression of socialisation skills, may produce indirect cascading effects that modulate parent-child interactions. The latter in turn may influence both vocal and perceptual development for language [9] [10].

The position held here will be necessarily speculative because we are unaware of studies that directly demonstrated gene-environment links in language, and because epigenetic mechanisms - the study of such interactions - have not been fully uncovered. However, the hypothesis is validly supported and motivated by the emergence of behavioural epigenetic, and the discovery of important gene-environment interactions related to complex behaviour. Behavioural and neural epigenetics are providing a framework for understanding how experiences and the environment influence the expression of genes in behaviour, cognition, personality, and mental health [11]. Influences of the same kind may also be in place in early language development, and we indicate new lines of research that might unveil such interactions. In Section 2, we briefly review known research on the genetics of language, mainly focusing on normally developing populations. In Section 3 we move to reviewing how parental language can influence language development in children. Finally, in Section 4 we chart tentative scenarios and imagine pathways through which genes and linguistic experiences or attachment profiles might mediate language development in the first years of life.

2. Genes for language

As discussed above, the human ability to acquire a language is likely to have an important genetic basis. The quest for a full genetic specification of language abilities is complicated by the fact that speech and language are almost certainly multi-genic highly complex traits. In other words, language skills are unlikely the results of a single gene. In addition, language phenotypes also appear to be associated with some genes with generalist effects influencing a range of cognitive abilities [3]. To date, researchers have been successful at identifying mutations on candidate genes related to language, and showed that individuals with such mutations correlated (but not necessarily exclusively) with difficulties to either learn or process language. Variation in certain linguistic abilities is underpinned by genetic variation between individuals, and developmental disorders affecting aspects of speech and language also have genetic roots [12]. For example, disruptions of the forkhead box protein P2 (FOXP2) inherited by a specific family in the UK were found to cause a rare speech disorder. This important finding implies that molecular changes can affect language development, and recent investigations of this gene are providing a template for connecting genetic variants and crucial human capacities. In particular, the human version of FOXP2 seems to be related to procedural knowledge. Rodents possess a non-human version of FOXP2, and when the humanized form of FOXP2 is placed in the genome of mice it promotes faster shift from relying on declarative to procedural learning in cases where the two systems compete [13].

To assess whether FOXP2 is linked not only to language disorders and procedural learning but also to language learning in normally varying populations, a team of scientists [14] trained English speaking adults to identify four distinct Mandarin Chinese lexical tones. The researchers also collected saliva samples from each of the participants, and later conducted a genotype analysis. They found that participants with a particular variation on the FOXP2 gene were faster and more accurate at learning the foreign speech tone contrasts. One interpretation of these findings is that learning new speech sounds involves using general cognitive strategies including procedural learning, which may be affected by the variation of the FOXP2 gene. Another group of researchers [15] was able to predict the final grades of college students following a three-week immersion second-language class using a combination of genetic and brain factors. In particular, genetic variations of the COMT gene and a measure of white matter reflecting the strength of the brain's communications network jointly accounted for nearly 50% percent of students' performance in the foreign language course. In other words, the variations of the COMT gene appeared to be related to modifications in the brain's white matter induced by the foreign language learning task. In a similar vein, Bates and colleagues [16] identified ROBO1 polymorphisms associated with variation in the ability to repeat non-words. This core ability is predictive of reading and spelling traits for both normally and atypically developing children with dyslexia. Another candidate gene potentially related to language is CNTNAP2. High levels of CNTNAP2 have been found in language related circuits, and polymorphisms in CNTNAP2 have been associated with altered functional asymmetry of language regions in healthy adults during a language processing task [17]. The studies discussed here are fundamental to extending the predictive role of genetics to normally varying language abilities, beyond identifying language disorders.

Besides genetic findings that shed light on adult language and learning, genetic effects have also been observed in early language acquisition. St Pourcain and colleagues [18] individuated a significant link between genetic changes near the ROBO2 gene and the number of different words known by children in the early years. The ROBO2 gene contains instructions for producing the ROBO2 protein. This protein directs chemicals in brain cells and other neuronal cell formations that may help infants develop language but also to vocalise and produce speech sounds by articulating facial and mouth muscles. The ROBO2 protein also closely interacts with other ROBO proteins that have previously been linked to problems with reading and remembering speech sounds. The study involved data from over 10,000 children. For a more comprehensive review of the genetic bases of language see [19].

3. Can attachment moderate or mediate gene expression in language development?

Genes and environment both contribute to the phenotype and behaviour, and represent nature and nurture, the poles of an age-old debate about what makes us who we are. Until recently they were seen as contributing independently (Figure 1, top panel), with genes single-handedly determining the nature of some of our characteristics. Recent research, however, is showing that neural and behavioural development can be determined by the interplay of genetic and environmental influences. In principle, there are two ways that this can happen; in what is typically referred to as Gene x Environment (G x E) interactions, genetic predispositions and environmental factors together shape individual behaviours. In our case in question, the environment would work as a moderator of individuals' genetic predisposition (Figure 1, centre panel); in particular, the strength and/or quality of verbal and non-verbal communication to the learning child would change the association between genes and language development.

Another (non-mutually exclusive) mechanism of interaction sees the environment act as a mediator, rather than a moderator, of the relationship between genes and language (Figure 1, bottom panel). Epigenetic modifications refer to chemical additions to DNA that can be transmitted from a parent cell to a daughter cell, potentially changing gene regulation and expression, but not involving changes in the base pairs that make up the genetic code of DNA itself. That is, epigenetic modifications influence gene activity and expression without changing genotype. DNA sequences can be likened to a dimmer switch that can be either on or off or partially on in any amount in between. How active a DNA segment is depends on its epigenetic state, which depends on factors like its context, including the history and environmental circumstances of the organism - here a child. Given that genetic activity levels change in different circumstances, the focus of research is slowly changing from what genes one has to what one's genes are doing. For example, it is irrelevant to have a particular gene or gene variant if that variant is turned off. In addition, generally genes must be expressed at a certain level, and having too little or too much of a particular gene expressed may not be advantageous for the organism. Behavioural epigenetics has started to show how our molecular biology influences our psychological states and how our psychological states influence our molecular biology. For example, early intimate relationships may have significant and long-lasting effects on a child's emotional, social, cognitive and physical development. Recent studies on gene-environment interactions have examined children's genotypes and measurements of their mothers' mental health status or parenting behaviour. These studies are providing new insights into the complex associations among infant attachment, temperament, mothers' mental health and parenting behaviours [20]. Behavioural and neural epigenetics seek to explain how nurture shapes nature, where nature refers to biological heredity and nurture refers to whatever historic events occur during the life-span (e.g., social-experience, diet and nutrition, and exposure to toxins). Behavioural epigenetics thus attempts to provide a framework for understanding how the expression of genes is influenced by experiences and the environment to produce individual differences in behaviour, cognition personality, and mental health. Briefly, epigenetic gene regulation involves changes other than to the sequence of DNA and includes changes to histones (proteins around which DNA is wrapped) and DNA methylation. These epigenetic changes can influence the growth of neurons in the developing brain as well as modify activity of the neurons in the adult brain. Together, these epigenetic changes on neuron structure and function can influence an organism's behaviour.

Are there G x E interactions or epigenetic effects on language development and, if so, how can we study them? Human children's caregivers provide feedback that is vital to infant learning. Language is best learned in social interactions between children and caregivers in the family or community. Virtuous learning processes can kick in when caregiver and child form dyadic interactive pairings. For example, prospective longitudinal studies show that maternal responsiveness to infants predicts when children achieve various language milestones [21] [22]. Much of what infants learn is organized serially (over time), and possibly hierarchically, including locomotion, social interaction and, ultimately, language. Linguistic patterns are learned and used over multiple timescales simultaneously. For example, speech is continuous, and children create the categories of the language they are acquiring by generalizing across (and creating exemplars of) repeated patterns found in continuous speech. The more and better such speech is the easier and better the child can make such generalizations, and so have better control of the language and the culture manifested in it. For example, in tickling games, a caregiver might use exaggerated prosodic contours and gestures while saying "I'm gonna get your nose! I got it! I got your nose! I'm gonna get your belly! I got your belly!" Partial repetition in caregiver's speech also facilitates comparison across utterances naturally highlights relevant linguistic units. The exaggerated speech and gestures provide salient information that reinforces correspondences between the varied items in the utterance (e.g. nose, belly) and their referents. Repeated pre-tickling gestures allow infants to predict the next step in the routine. The salient outcome of being tickled enables infants to confirm predictions about caregivers' speech and actions. Over developmental time, caregivers adjust their own role and the infant's role in the social routines, encouraging infants to increase their contribution to the game as infants' abilities improve (i.e. scaffolding).

It has been proposed that together, the availability of structural and social cues explains the robust effects of socially guided learning on the development of adaptive skills by facilitating the reliable identification of patterns of information in the environment. For example, infants' babbling facilitates phonological learning because caregivers' responses to early speech tend to be appropriately structured and temporally coordinated with child utterances [23] and infants learn to produce new vocal patterns from caregiver speech that is contingent on infant production [10] [24]. New phonological patterns are rapidly learned and entrenched as this process is iterated across utterances. Conversely, in prelinguistic vocal production, infants fail to learn new forms from non-contingent exposure to speech. Thus, in the absence of responsive caregiving—or if responses are unreliable or inappropriate—the brain's architecture may not form as expected, which can lead to disparities in learning and behavior.

That parental levels of attachment affect language development is now attested by several studies. Significant disparities exist between children from advantaged and disadvantaged families. By 24 months there is a 6-month gap between SES (socioeconomic status) groups in processing skills relevant to language development [25]. In a seminal study, Hart and Risley [26] observed a positive relation between the amount and quality of parent talk and the children's vocabulary size across families from different demographic backgrounds. In particular, by the age of four, thirty million fewer words would have been heard by a child from a poor home, compared with children whose parents are professionals. This initial finding was corroborated by recent studies. For example, the amount of child-directed speech predicted typical children's receptive vocabulary at 30 and 42 months [7]. In addition to the quantity of language input, content and quality of language input also affect child language development. In one study [4] the number of different words, the mean length of utterance, as well as the syntactic complexity of maternal speech predicted productive vocabulary in typically developing 2-year-olds. Thus, not only the quantity but also the quality and diversity of words that parents use are associated with the size of children's expressive vocabulary. Research has also shown that the gap in cognitive achievement is not narrowed through formal education, suggesting a critical optimum period in early childhood cognitive development. The work of Marc Bornstein and colleagues shows this to be the case in low- as well as high-SES families starting in the second year of life and continuing to adolescence [6] [5].

It has been proposed that reciprocal "serve and return" interactions with adults facilitate positive epigenetic modifications [27] in the following way. Infants and young children naturally reach out for interaction through babbling, facial expressions, and gestures, and adults can respond with the same kind of vocalizing and gesturing back at them. This back-and-forth process is fundamental to the wiring of the brain, especially in the earliest years. Yet epigenetic effects in socially guided language learning have not been properly investigated.

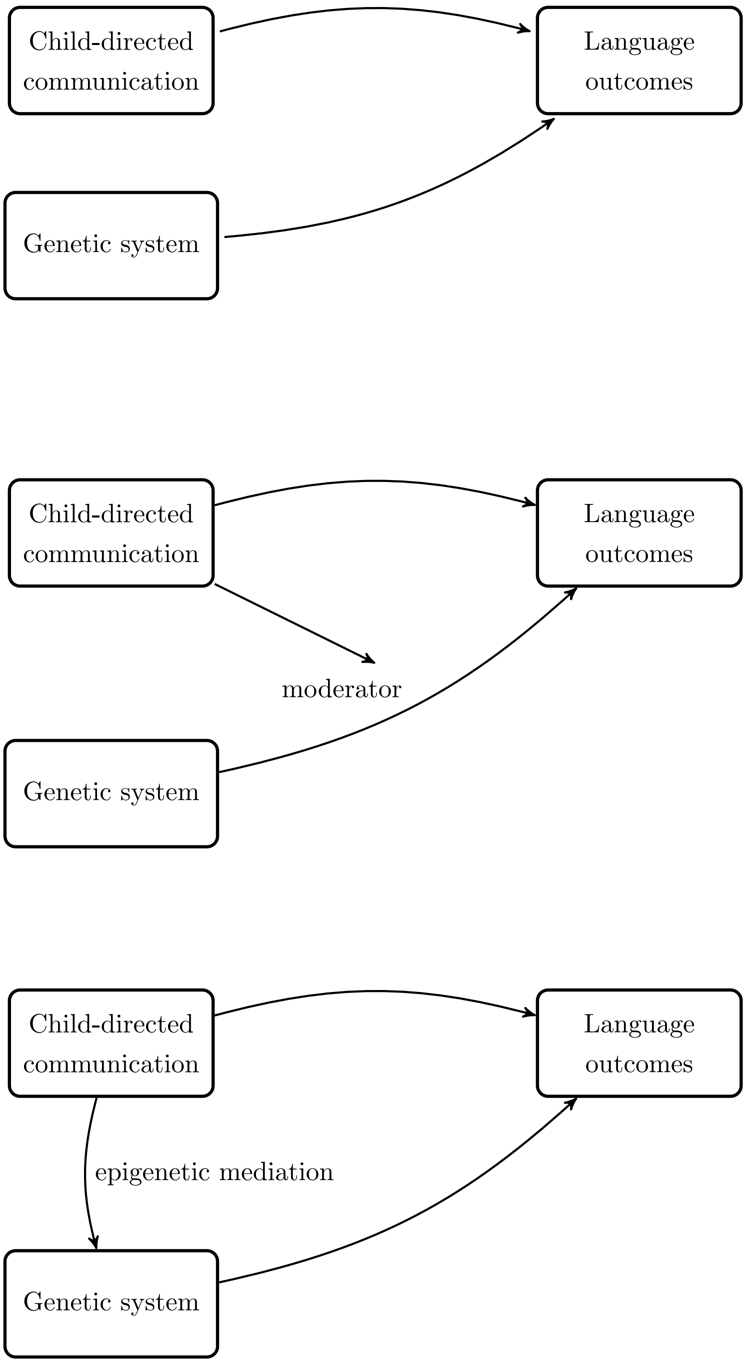

Figure 1. *Three conceptual models of the role of genes and environment (here,caregiver communication) in shaping language development. Top: Environment and genes contribute independently to language outcomes. Centre: Environment moderates the effect of genetic predispositions to language. Bottom: Environment mediates the role of genes.*

4. Possible Gene x Environment and epigenetic pathways to language development

There are several potential ways that such effects could emerge, and we consider two here by way of example: 1) Epigenetic effects on procedural learning impacting language learning; 2) Epigenetic effects on levels of stress impacting language learning.

The first type of epigenetic effect that one might expect to find relates to procedural/statistical learning. Because language appears to be linked to the ability to procedurally discover statistical regularities and patterns in speech, parents providing richer statistical input by way of partial self-repetitions and expansions to the child may boost the genetic bases of procedural learning. A research group led by Shimon Edelman [28] [29] have proposed a framework by which young children learn by integrating, over a restricted time window, prominent statistical regularities with contextual cues such as social interaction and reward. Statistical significance is realized by recognizing patterns of co-occurrences that emerge above background noise. Importantly, socially embedded learning weights such statistical regularities by their co-occurrence with supporting contextual cues. For example, developmental studies indicate that infants learn structures that appear in subsequent partial repetitions particularly efficiently (H. Waterfall, PhD thesis, University of Chicago, 2006). Parents commonly use partial repetition and expansion of child utterances, especially when children's speech is ungrammatical or incorrect [30] [31]. Children make immediate corrections to their speech in response to parent expansions, often incorporating parents' corrections [30] [32]. Partial repetitions that are contingent in time with a child's vocalisation can facilitate parsing even for elements that occur outside them [33]. In infants, partial repetitions might support learning structure at multiple levels, from detecting word boundaries to associating labels with objects to acquiring grammatical constructions. In relation to epigenetic effects, it is plausible to expect richer parental input to positively affect procedural/statistical learning in children. As FOXP2 is involved in procedural learning, poor parental linguistic scaffolding might affect the expression of FOXP2 in the first years of life, and this epigenetic effect might in turn affect the ability of the child to extract statistical patterns from parental speech. Likewise, as the expression of the ROBO2 gene appears to be linked to the number of words spoken by children, one might expect parental levels of language scaffolding to impact on the expression of ROBO2 during language development.

As we discover more about genes implicated in language and communication, we will be able to project more qualified hypotheses for gene-environment interaction. For example, Foxp2 regulates the activity of several hundred genes 'downstream', including many that have non-language related functions. Among the ones that do have a relation to language appear Srpx2 and Cntnap2. Sia and colleagues [34] were able to vary the activity of the Srpx2 gene in baby mice and found that its inhibition led the mice to squeal less, thus effectively affecting the capacity for alarm call communication in the rodents. It is still unknown whether the Foxp2 - Srpx2 cascade affects brain cells related to language processing or nerve cells that control muscles involved in talking. Nonetheless, from an epigenetic perspective Srpx2 might be inhibited in language development whenever parents do not engage sufficiently in communication activities. A recent study found that television exposure interfered with babies' and toddlers' developing language skills by reducing verbal interactions with parents by 500-1000 words per hour [35]. Having a television on within earshot of young children diminished their exposure to adult words, their own vocalizations, and the conversational turns in which they engage. A possible epigenetic effect might thus be the reduction of Srpx2 gene expression in young children exposed to prolonged hours of television as well as similar 'silencing' media such as tablets and smartphone apps. These devices have become so much a part of everyday's family lives that the American Academy of Paediatrics has issued recommendations that children not watch TV or videos before the age of two. Providing evidence that early media exposure not only affects children's phenotype but also their epigenome (the set of epigenetic markers through the whole genome) would add strong evidence that parental control of media is essential to healthy language development.

We have proposed how differences in quantity and/or quality of linguistic input might trigger epigenetic effects on language development. A different yet equally possible epigenetic pathway may involve the varying quality of the social interaction and bonding the child receives from caretakers, which impacts the overall quality of daily communication between parent and child. High levels of stress often contributed by one of the parents may weaken the architecture of the developing brain, which can lead to lifelong problems in learning, behaviour, and physical and mental health. Experiencing stress is an important part of healthy development, and activation of the stress response produces a wide range of physiological reactions that prepare the body to deal with threat or uncomfortable situations. When these responses remain activated at high levels for significant periods of time, without supportive relationships to help calm them, toxic stress results. This can impair the development of neural connections, especially in the areas of the brain dedicated to higher-order skills including language. A recent study [36] purported to show that epigenetic modification of the structural gene for oxytocin (OXT) is an important factor associated with individual differences in social processing, including self-report, behaviour, and brain function and structure in humans. Similarly, Esposito and colleagues [37] found a gene by environment interaction for susceptibility to social distress. Adult participants with a genetic risk factor (A carriers) with a history of high paternal overprotection showed higher heart rate increase than those without this risk factor (G/G genotype) to social distress. Social vocalization from mother to daughter stimulates oxytocin release and reduces stress responses in humans [38]. These results suggest that social signals from the mother stimulate the oxytocin system in infants. By extension, given the crucial role of social interaction in learning salient statistically significant structures, suboptimal levels of oxytocin in the child might hinder mutual communication between parent and child, resulting in suboptimal support of statistical/procedural learning of language.

5. Conclusion

The human capacity for language appears unique in the natural realm. It has been traditionally seen as partly innate and partly learned, and a divide and conquer approach has been adopted in which one factor - genes or environment - was given predominant emphasis and one was pitted against the other. Progress in understanding how the innate and learned components work together may come from understanding epigenetic mechanisms controlling the expression levels of genes [2] as a function of environmental factors. We have charted possible scenarios in which epigenetic effects on language development might be triggered by differential attachment practices in caregiver-child interactions in the early years. These scenarios are still to a large extent speculative, but do rely on insights from recent important epigenetic findings. Several open questions remain at present. The first is of a practical nature, namely how to study the epigenetics of language empirically in normally developing children. It seems clear that a multi-method approach will be needed, involving DNA sampling of mother and child coupled with psychophysiological measures of attachment, behavioural, and brain measure of cognitive and linguistic development. In particular, novel measures of language behaviour coupling such as language style matching (LSM) introduced by Rasmussen and colleagues (this issue) and variation sets across the parent-child dyad [28] may in the future be correlated with physiological measures of anxiety and levels of oxytocin, which in turn may be related to genetic expression of specific targeted genes.In this quest, many genes can be initially targeted in exploratory studies. The literature reviewed above suggests obvious initial candidates in FOXP2, SRPX2, ROBO2, ROBO1 and COMT. However, these genes likely participate with many different genetic systems to support language development because complex traits like language are multifactorial. They result from multiple genetic loci, genetic mechanisms and environmental factors.

In addition, research indicates that some genes can only be modified epigenetically during certain sensitive periods of development, while other genes are open to alterations throughout life. Are the main genes implicated in language of the former or latter type? A third problem to tackle will be avoiding conflating attachment effects on cognitive and language development with truly epigenetic effects. In that respect, [39] provides cautionary tales that cautiously mitigate the hype for putative epigenetic findings. Regardless, the study of the effects of attachment and bonding in language development is expected to be ripe with future discoveries.

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